

Winter warming in the Arctic from mid-latitude particulates

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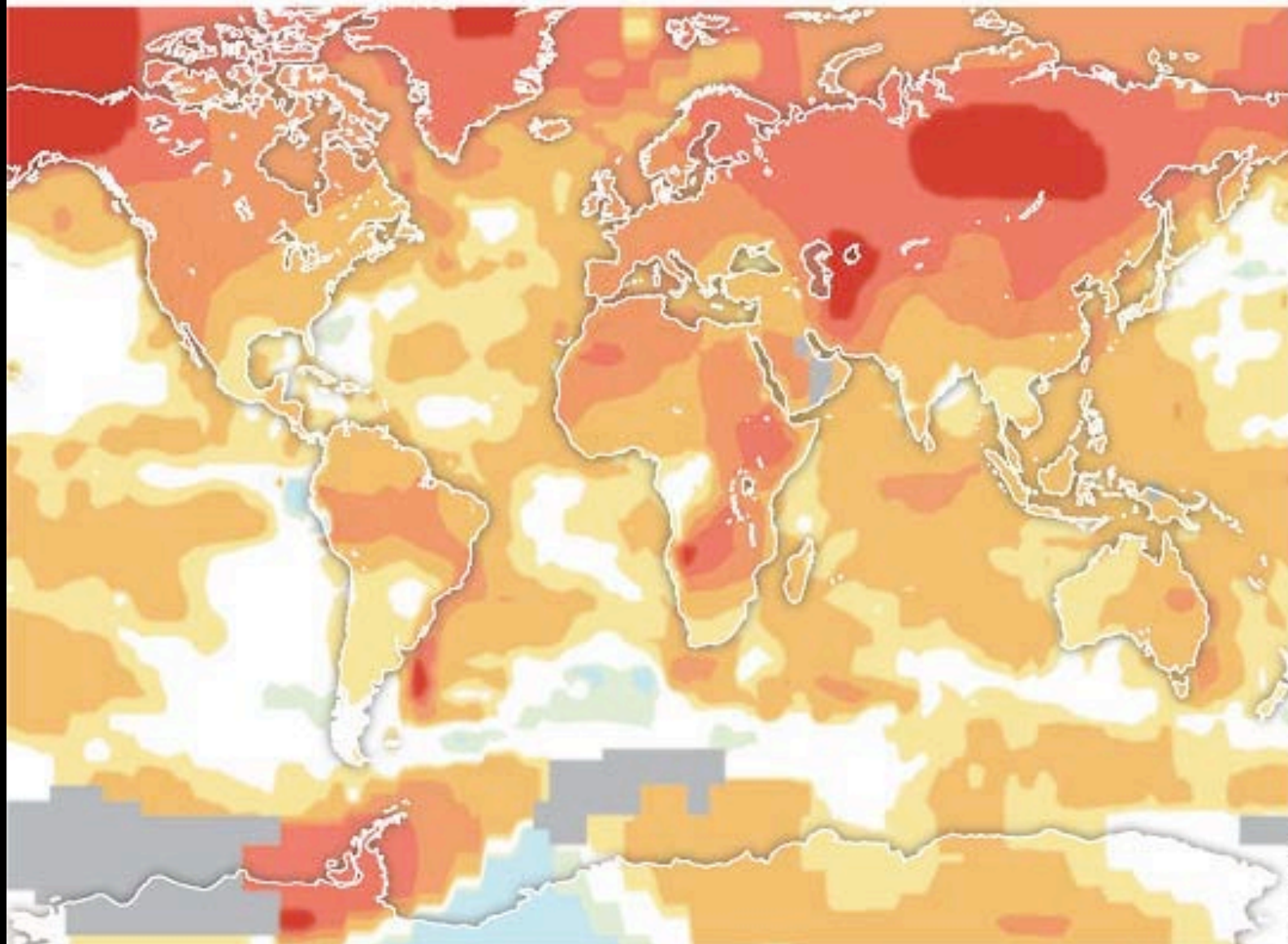
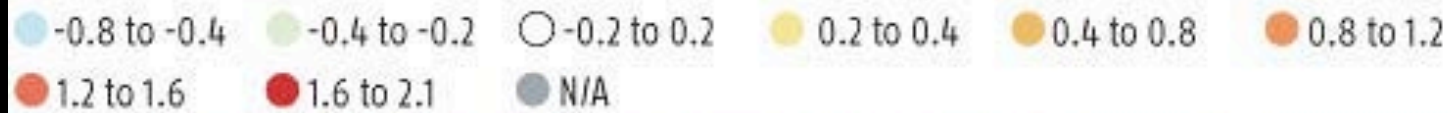
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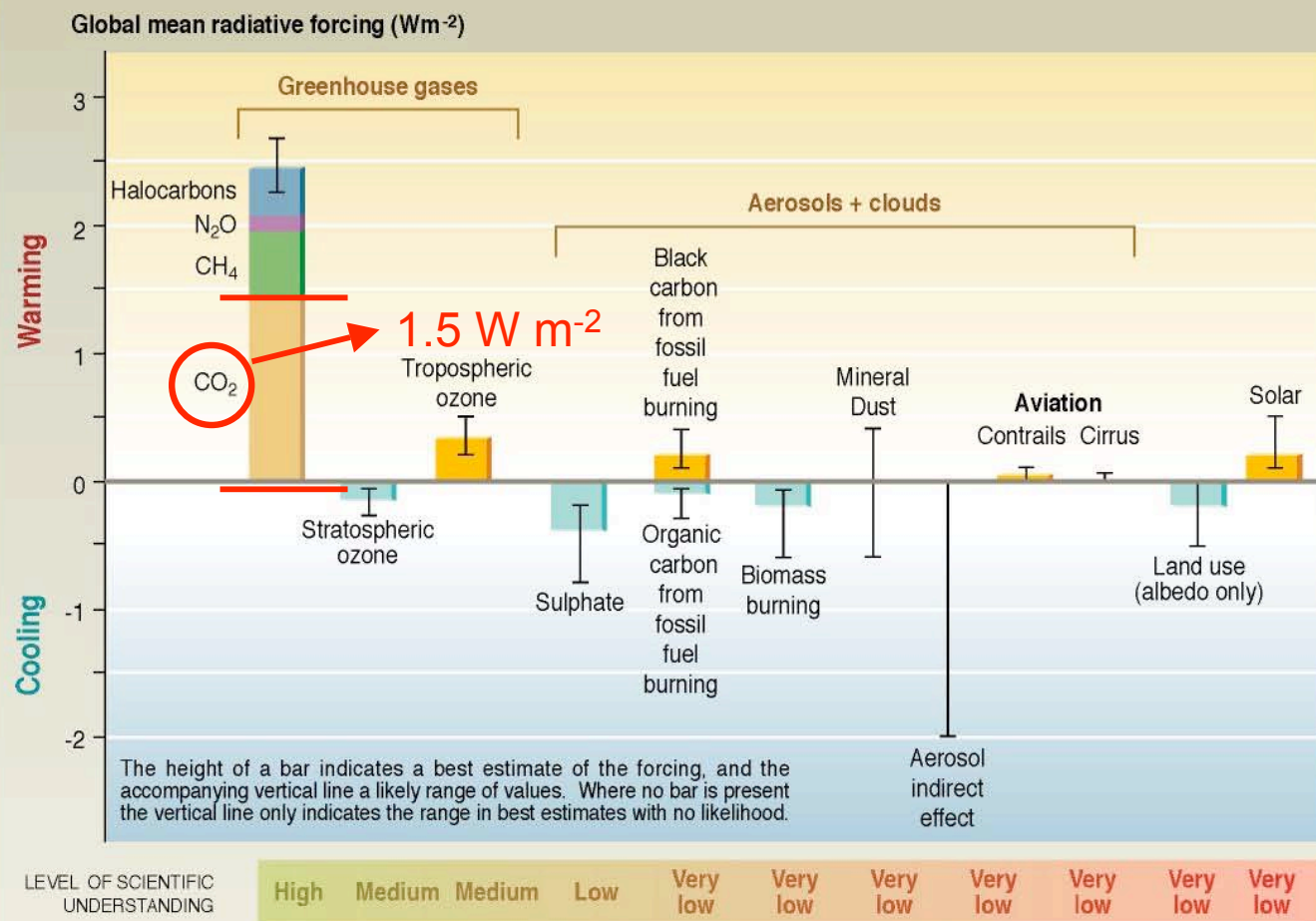
CLIMATE CHANGE HOTSPOTS

Temperature changes over the past 30 years (°C)



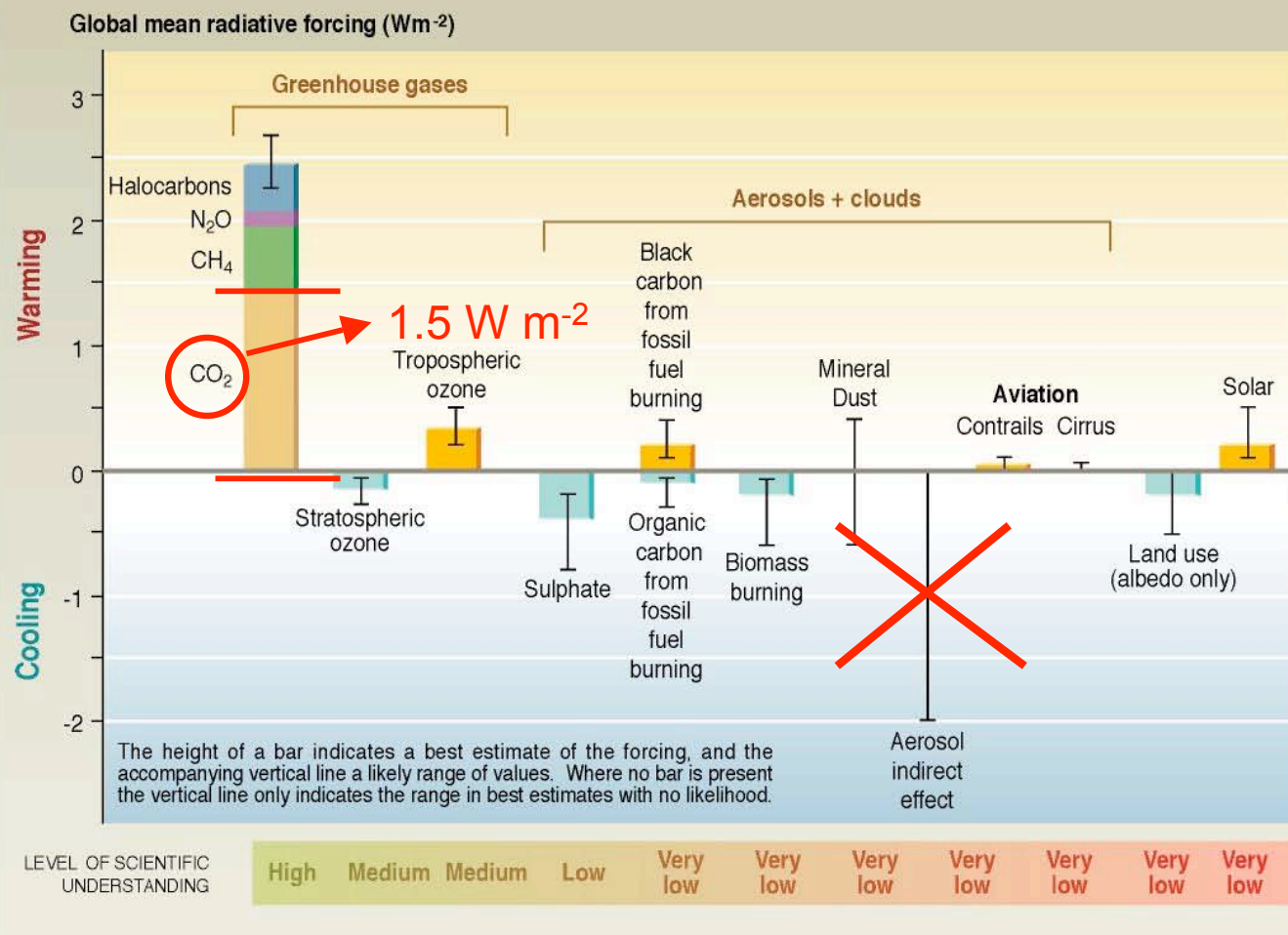
SOURCE: PNAS

Anthropogenic and natural forcing of the climate for the year 2000, relative to 1750



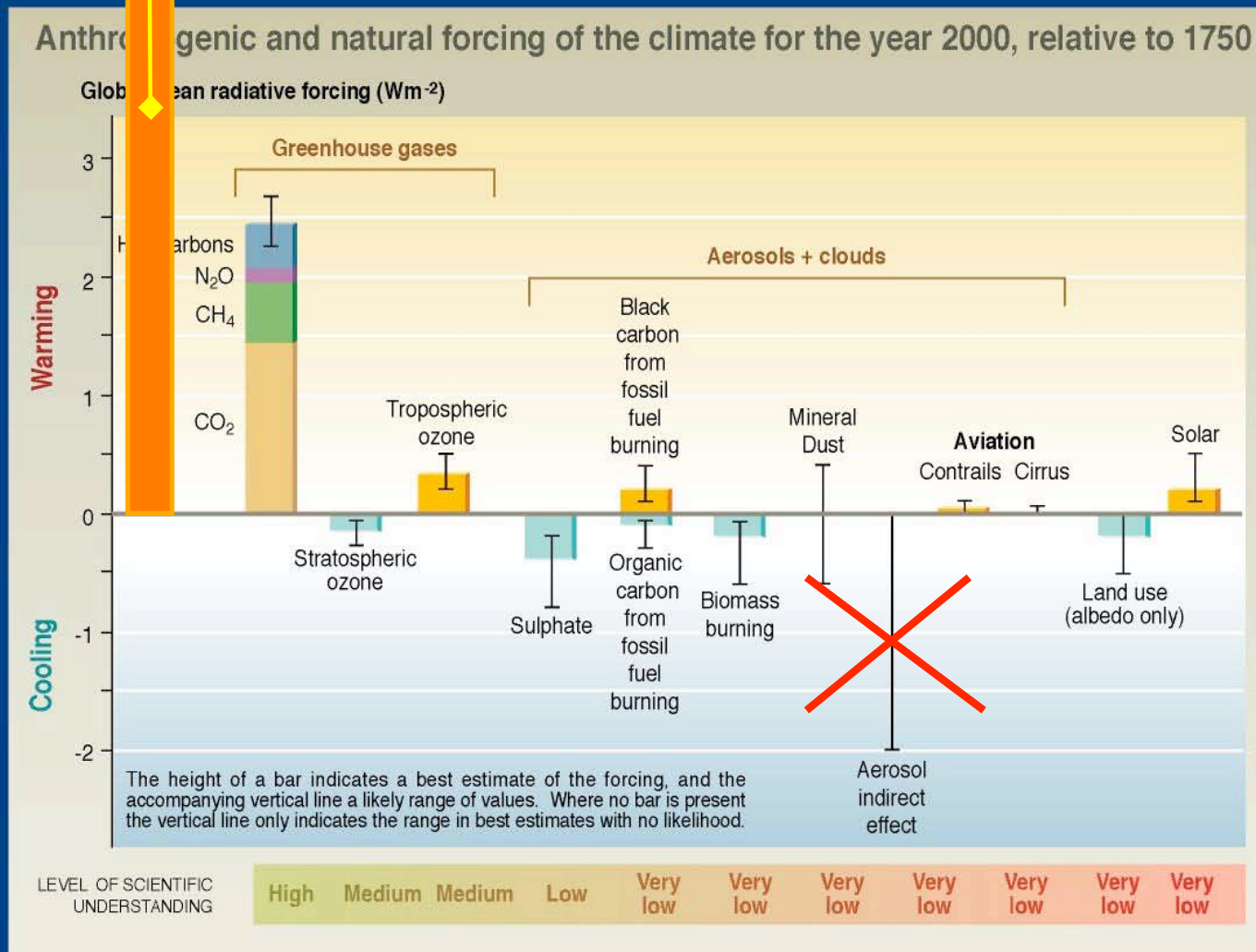
SYR - FIGURE 2-2

Anthropogenic and natural forcing of the climate for the year 2000, relative to 1750



SYR - FIGURE 2-2

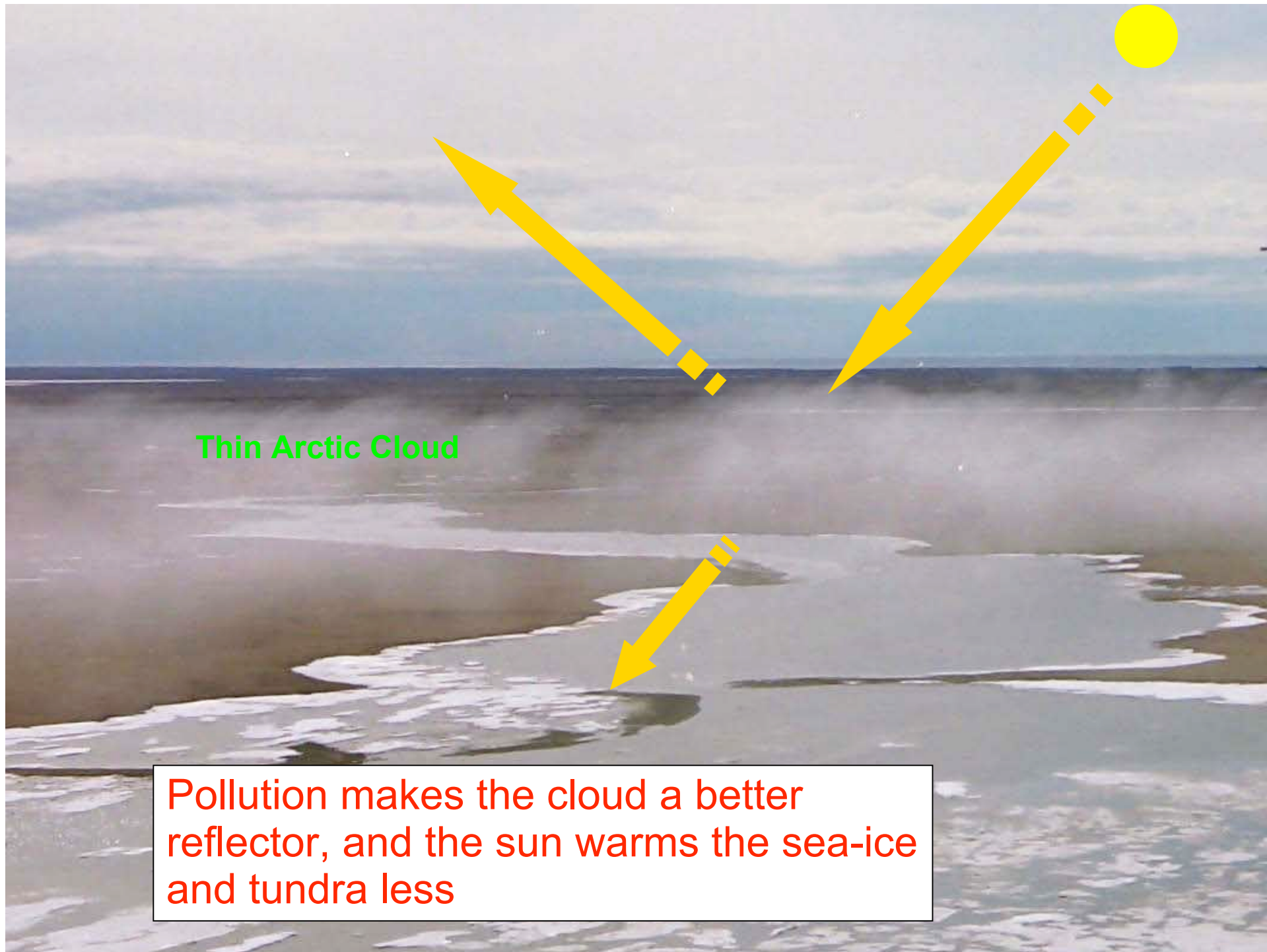
Aerosol indirect effect in the Arctic
3.3 to 5.5 W m⁻² when polluted and cloudy



SYR - FIGURE 2-2



Thin Arctic Cloud



Thin Arctic Cloud

Pollution makes the cloud a better reflector, and the sun warms the sea-ice and tundra less



Thin Clean Arctic Cloud
Poor blanket

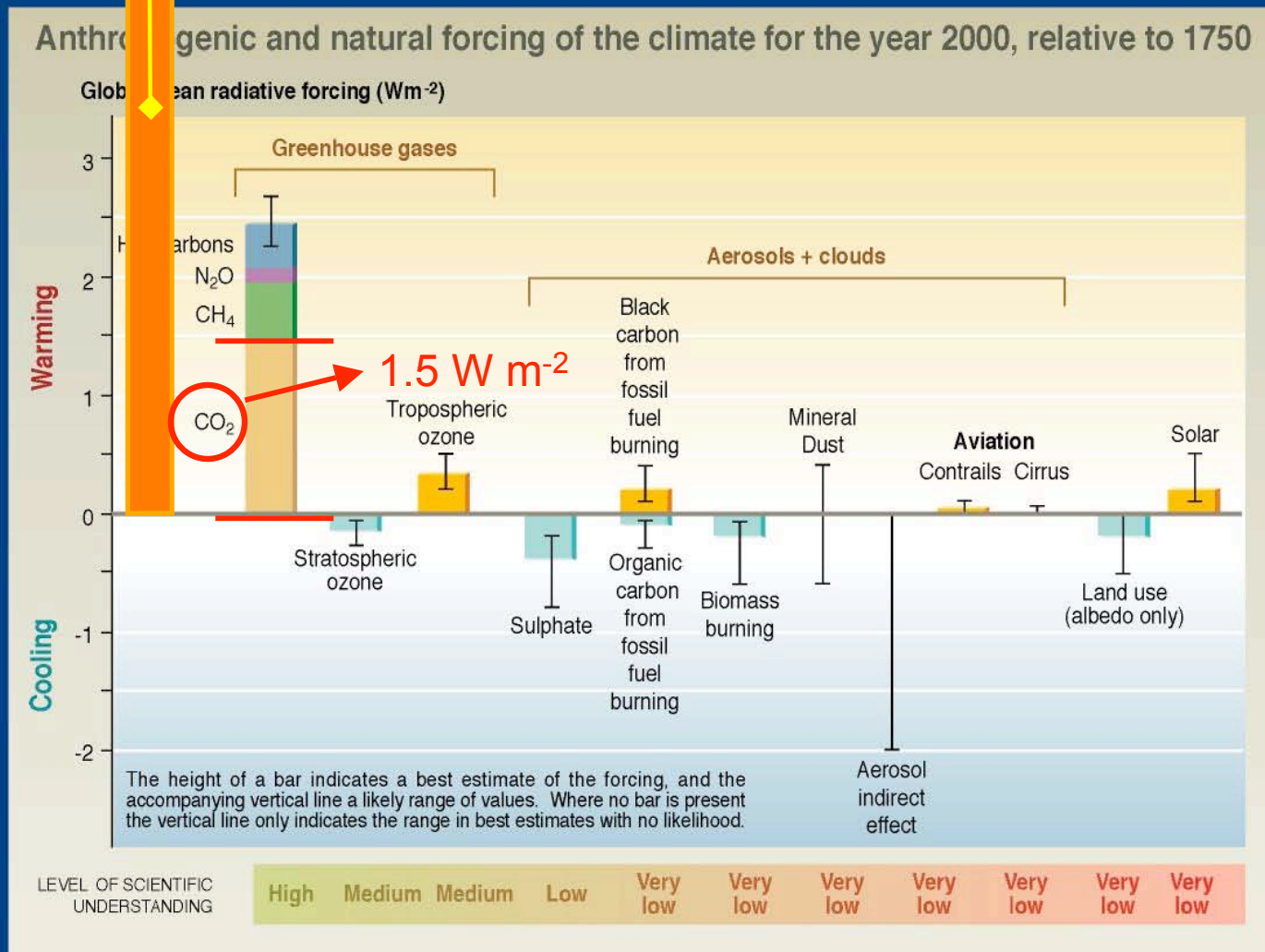




Thin Polluted Arctic Cloud
Good blanket

Pollution makes the cloud a better blanket. Less heat escapes to space, which makes the Arctic surface warmer

The forcing from this particulate pollution effect 3.3 to 5.5 W m^{-2} when polluted and cloudy



SYR - FIGURE 2-2

Where work is needed

- ✓ We have identified a *sensitivity* in the Arctic climate system
- ✓ Model studies are required to evaluate the *effects*





Current climate models cannot reproduce the described effect. The effect applies to very thin Arctic clouds. Climate models cannot easily create clouds this thin.

What is the history?



Adolf Erik Nordenskjöld 1876 in Greenland:

“The sky was covered with a thin veil of clouds, through which the sun shone warmly, at times even scorchingly. From time to time this veil of clouds, or haze, descended to the surface of the ice, and hid the view over the expanse; but it was, remarkably enough, not wet, but *dry*, -- yes, so dry that our wet clothes absolutely dried in it.”

48TH CONGRESS, }
2d Session. }

HOUSE OF REPRESENTATIVES.

{ EX. DOC.
No. 44 }

REPORT

OF THE

INTERNATIONAL POLAR EXPEDITION

TO

POINT BARROW, ALASKA,

IN RESPONSE TO

THE RESOLUTION OF THE HOUSE OF REPRESENTATIVES
OF DECEMBER 11, 1884.

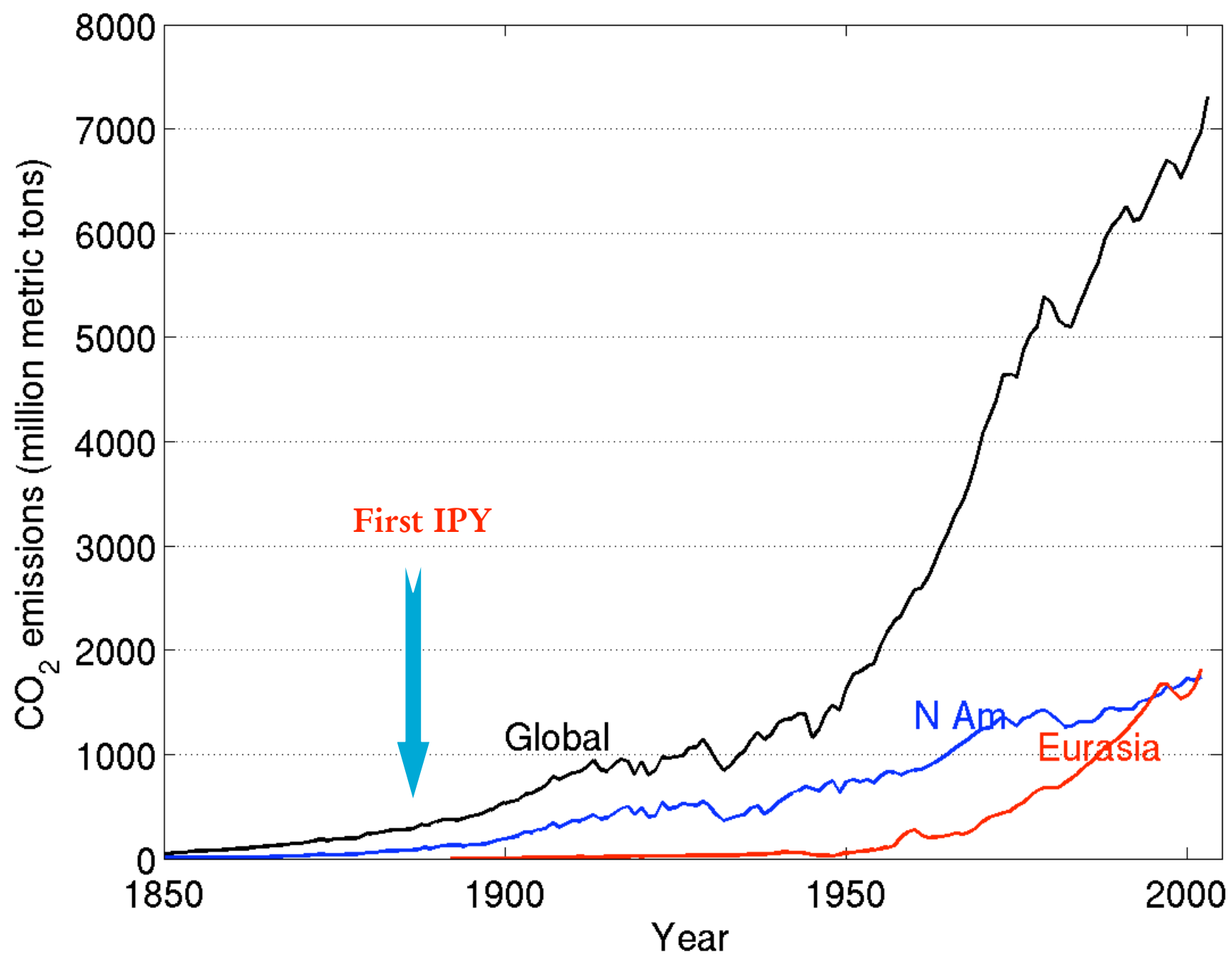
WASHINGTON:
GOVERNMENT PRINTING OFFICE
1885.

Statement showing the amount, kind, and direction of clouds, and amount and

[Washington mean time. Correction reduced to mean local time, - 5 hours, 17 minutes. Precipitation is given in inches. In this

Date.	1 a. m.		2 a. m.		3 a. m.		4 a. m.		5 a. m.		6 a. m.	
	Amount, kind, and direction of clouds.	Precipitation.	Amount, kind, and direction of clouds.	Precipitation.	Amount, kind, and direction of clouds.	Precipitation.	Amount, kind, and direction of clouds.	Precipitation.	Amount, kind, and direction of clouds.	Precipitation.	Amount, kind, and direction of clouds.	Precipitation.
1883.												
Feb. 1	9 st.	0	10 st.	0	3 st.	0	Lt. haze. 3 st.	0	Lt. haze. 1 st.	0	0	0
Feb. 2	D. haze. 9 st. D. haz. 0	0	D. haze. 9 st. D. haz. 0	0	D. haze. 9 st.	0	D. haze. 7 st. D. haz. 0	0	D. haze. D. haze	0	D. haze. D. haze	0
Feb. 3	7 st.	0	D. haze. 9 st.	0	D. haze. 7 st. D. haz. 0	0	D. haze. 8 st. D. haz. 0	0	Lt. haze. 1 st.	0	0	0
Feb. 4	D. haze. 3 st.	0	D. haze. 10 st.	0	10 st.	0	10 st.	0	Lt. haze. 5 st.	0	Lt. haze. 4 st.	0
Feb. 5	10 nim.	0	10 nim.	0	10 nim.	0	10 nim.	0	10 nim.	0	10 nim.	0
Feb. 6	7 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0
Feb. 7	D. haze. 4 st. D. haz. 0	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0
Feb. 8	D. haze. 6 st. D. haz. 0	0	D. haze. 5 st. D. haz. 0	0	D. haze. 3 st. D. haz. 0	0	0	0	0	0	0	0
Feb. 9	10 nim.	0	10 nim.	0	10 nim.	0	10 nim.	0	10 nim.	0	10 nim.	0
Feb. 10	10 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0
Feb. 11	0	0	0	0	0	0	0	0	0	0	0	0
Feb. 12	Lt. haze. 2 st.	0	Lt. haze. 3 st. D. haz. 0	0	D. haze. 8 nim.	0	D. haze. 8 nim.	0	D. haze. 9 nim.	0	10 nim.	0
Feb. 13	D. haze. 8 nim.	0	4 cir. st. 3 st.	0	1 st.	0	1 cir. st. 1 st.	0	1 st.	0	2 st.	0
Feb. 14	10 nim.	0	10 nim.	0	10 nim.	0	D. haze. 6 nim. NW. f.	0	4 st.	0	1 st.	0
Feb. 15	10 nim.	0	10 nim.	0	10 nim.	0	3 cum. 5 st.	0	1 cum. 9 st.	0	10 st.	0
Feb. 16	0	0	1 cir. st. 1 st.	0	1 cir. st. 1 st.	0	1 cir. st. 7 st. NW. f.	0	2 cir. st. 5 st.	0	1 cir. st. 3 st.	0
Feb. 17	10 st.	0	10 st.	0	D. haze. 4 st. D. haz. 0	0	1 cir. st. 4 st.	0	2 cir. cum. 2 st.	0	5 cum. 4 st.	0
Feb. 18	D. haze. 8 st. D. haz. 0	0	D. haze. 9 st. D. haz. 0	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0
Feb. 19	10 st.	0	10 st.	0	10 st.	0	D. haze. 9 st.	0	Lt. haze. 3 st.	0	2 st.	0
Feb. 20	9 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0
Feb. 21	8 st.	0	10 st.	0	1 cir. 1 cir. st. 5 st. S. f.	0	1 cir. 2 cir. st. 3 st. S. f.	0	2 cir. 2 cir. st. 3 st. S. f.	0	5 cir. st. 2 st.	0
Feb. 22	1 cir. st.	0	1 cir. st.	0	1 cir. st.	0	1 st.	0	0	0	0	0
Feb. 23	1 cir. st.	0	1 cir. st. 1 st.	0	1 cir. st. 1 st.	0	1 cir. st.	0	Lt. haze.	0	D. haze. D. haze.	0
Feb. 24	1 cir. st.	0	1 st.	0	1 cir. st.	0	0	0	0	0	0	0
Feb. 25	0	0	0	0	1 cir. st.	0	1 cir. st.	0	1 st.	0	0	0
Feb. 26	0	0	0	0	0	0	0	0	0	0	0	0
Feb. 27	2 st.	0	D. haze. 4 st. D. haz. 0	0	Lt. haze. 3 st.	0	Lt. haze. 2 st. D. haz. 0	0	Lt. haze. 1 st.	0	Lt. haze. 3 st.	0
Feb. 28	10 nim.	0	D. haze. 8 st.	0	10 st.	0	D. haze. 8 st. D. haz. 0	0	D. haze. D. haze.	0	D. haze. 9 st.	0
	5.92		6.64		6.11		5.82		4.42		4.67	
Date.	1 p. m.		2 p. m.		3 p. m.		4 p. m.		5 p. m.		6 p. m.	
	Amount, kind, and direction of clouds.	Precipitation.	Amount, kind, and direction of clouds.	Precipitation.	Amount, kind, and direction of clouds.	Precipitation.	Amount, kind, and direction of clouds.	Precipitation.	Amount, kind, and direction of clouds.	Precipitation.	Amount, kind, and direction of clouds.	Precipitation.
1883.												
Feb. 1	1 cir. cum. 1 st.	0	1 st.	0	1 st.	0	0	0	0	0	1 st.	0
Feb. 2	Dense haze. 5 st.	0	Lt. haze. 6 st.	0	1 cir. 5 st. SW. f.	0	1 cir. 7 st. SW. f.	0	1 ci. 5 st. SW. f. D. fog.	0	D. haze. D. fog.	0
Feb. 3	9 st.	0	10 st.	0	10 nim.	0	10 nim.	0	4 cir. 5 st. SW. f.	0	10 st. SSW. f.	0
Feb. 4	1 cir. cum. 8 st.	0	1 cir. cum. 8 st.	0	1 cir. cum. 7 st. SW. f.	0	2 cir. 4 st. SW. f.	0	5 cir. st. 3 st. SW. f.	0	4 cir. st. 6 st. SW. f.	0
Feb. 5	10 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0
Feb. 6	1 st.	0	1 cir. 1 st.	0	1 cir. 1 st.	0	2 cir.	0	3 cir. 1 st.	0	4 cir. 1 st.	0
Feb. 7	10 st.	0	10 nim.	0	10 nim.	0	9 st.	0	5 st.	0	2 st.	0
Feb. 8	2 st.	0	4 st.	0	8 st.	0	10 nim.	0	10 nim.	0	10 nim.	0
Feb. 9	10 nim.	0	9 st.	0	9 st.	0	8 st.	0	9 st.	0	10 st.	0
Feb. 10	Lt. haze. 4 st. WNW. f.	0	5 st. WNW. f.	0	5 st. W.	0	4 st. W.	0	3 st. W.	0	3 st. W.	0
Feb. 11	0	0	0	0	0	0	0	0	0	0	0	0
Feb. 12	10 nim.	0	10 nim.	0	10 nim.	0	10 nim.	0	10 nim.	0	10 nim.	0
Feb. 13	8 st.	0	8 st.	0	9 st.	0	9 st.	0	5 st.	0	1 cir. st. 4 st.	0
Feb. 14	10 st.	0	10 st.	0	8 st.	0	1 cir. 4 st.	0	1 cir. 4 st.	0	1 cir. 6 st.	0
Feb. 15	10 st.	0	10 st.	0	9 st.	0	8 st.	0	8 st.	0	8 st.	0
Feb. 16	1 cir. 1 st.	0	1 cir. 3 st.	0	2 cir. 2 st.	0	2 cir. 2 ci. st. 1 st.	0	3 cir. 3 cir. st. 1 st.	0	7 cir. 1 st.	0
Feb. 17	2 st.	0	1 st.	0	1 st.	0	1 st.	0	1 st.	0	10 st.	0
Feb. 18	10 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0
Feb. 19	1 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0	10 st.	0
Feb. 20	3 st.	0	1 st.	0	1 cir. 1 st.	0	1 cir. 3 st.	0	1 ci. 2 ci. st. 3 st. SW. f.	0	1 ci. 1 ci. st. 4 st. SW. f.	0
Feb. 21	10 st.	0	10 nim.	0	10 st.	0	10 st.	0	10 st.	0	10 nim.	0
Feb. 22	0	0	0	0	0	0	0	0	0	0	1 st.	0
Feb. 23	10 nim.	0	4 cir. 4 st.	0	2 cir. 7 st.	0	1 cir. 8 st.	0	3 cir. 6 st.	0	4 cir. 4 st.	0
Feb. 24	1 st.	0	1 st.	0	0	0	0	0	0	0	1 cir.	0
Feb. 25	1 st.	0	1 cir. 1 st.	0	1 cir. 1 st.	0	1 cir. 1 st.	0	0	0	0	0
Feb. 26	0	0	0	0	0	0	0	0	0	0	1 cir. 2 st.	0
Feb. 27	2 cir. cum. 6 st. SE. f.	0	1 ci. cum. 4 st. SE. f.	0	3 cir. cum. 5 st. SE. f.	0	8 st. SE. f.	0	7 cir. 2 st. SE. f.	0	5 cir. 2 st.	0
Feb. 28	1 cir. 7 st. SSW. f.	0	1 cir. 8 st. SSW. f.	0	10 nim.	0	2 cir. 6 nim.	0	10 st.	0	10 nim.	0
	5.57		5.69		6.14		5.92		6.03		5.92	

Date.	1 a. m.		2 a. m.		3 a. m.	
	Amount, kind, and direction of clouds.	Precipitation.	Amount, kind, and direction of clouds.	Precipitation.	Amount, kind, and direction of clouds.	Precipitation.
1883.						
Feb. 1	9 st. 0	—	10 st. 0	00	3 st. 0	00
Feb. 2	D. haz. 9 st. D. haz. 0	00	D. haz. 9 st. D. haz. 0	00	D. haze. 9 nim. 0	—
Feb. 3	7 st. SW. 0	00	D. haze. 9 st. 0	00	D. haz. 7 st. D. haz. 0	00
Feb. 4	D. haze. 3 st. 0	00	D. haze. 10 st. 0	00	10 st. 0	00
Feb. 5	10 nim. 0	02	10 nim. 0	03	10 nim. 0	03
Feb. 6	7 st. 0	00	10 st. 0	00	10 st. 0	00
Feb. 7	D. haz. 4 st. D. haz. 0	00	10 st. 0	00	10 st. 0	00
Feb. 8	D. haz. 6 st. D. haz. 0	00	D. haz. 5 st. D. haz. 0	00	D. haz. 3 st. D. haz. 0	00
Feb. 9	10 nim. 0	01	10 nim. 0	01	10 nim. 0	01
Feb. 10	10 st. 0	00	10 st. 0	00	10 st. 0	00
Feb. 11	0 0	00	0 0	00	0 0	00
Feb. 12	Lt. haze. 2 st. 0	00	Lt. haz. 3 st. D. haz. 0	00	D. haze. 8 nim. 0	—
Feb. 13	D. haze. 9 nim. 0	01	4 cir. st. 3 st. 0	—	1 st. 0	00
Feb. 14	10 nim. 0	—	10 nim. NW. †	—	10 nim. NW. †	01
Feb. 15	10 nim. W. †	—	10 nim. W. †	—	10 nim. W. †	—
Feb. 16	0 0	00	1 cir. st. 1 st. 0	00	1 cir. st. 1 st. 0	00
Feb. 17	10 st. 0	00	10 st. 0	00	D. haz. 4 st. D. haz. 0	00
Feb. 18	D. haz. 8 st. D. haz. 0	00	D. haz. 9 st. D. haz. 0	00	10 st. 0	00
Feb. 19	10 st. 0	00	10 st. 0	00	10 st. 0	00
Feb. 20	9 st. NW. †	00	10 st. NW. †	00	10 st. NW. †	00
Feb. 21	8 st. SSE. †	00	6 st. S. †	00	1 cir. 1 cir. st. 5 st. S. †	00



Questions

- ✓ Has Arctic aerosol warming been around for a long time?
- ✓ If so, is the very recent warming not due to aerosol?

Questions

- ✓ Are changes in industrial particulate emissions independent of changes in industrial CO₂ emissions?
- ✓ Or are does one go up when the other goes down?

Summary

- ✓ Industrial particulates make Arctic clouds better “blankets” in winter. The forcing appears comparable to the carbon dioxide forcing.
- ✓ Currently, climate models do not simulate this physics. Finer vertical resolution may be needed.
- ✓ Arctic aerosol pollution was likely high 100+ years ago. This was when industrial CO₂ emissions were still low.

Support from National Science Foundation.

Reference: Garrett and Zhao, *Nature* (2006)